

SECONDARY ENRICHMENT

SECONDARY ENRICHMENT IN CHALCOPYRITE (COPPER) DEPOSITS

- **Secondary enrichment:** is an ore concentrating process that occurs when metals are leached from surface rocks and precipitated just below the water table.
- **Leaching:** is where elements are dissolved from rocks and carried downwards in solution.
- **A Gossan:** is an impermeable cap of iron oxides at the surface.
- **Oxidising:** describes conditions which are oxygen-rich, allowing elements to combine with oxygen to form oxides.
- **Reducing:** describes conditions which are oxygen-poor, anoxic conditions.
- **An enriched deposit:** is a zone of high grade ore just below the water table, formed by secondary enrichment.
- **A porphyry:** is a large igneous intrusion below a volcano with a porphyritic texture.

In order for an ore deposit to exist, natural geological processes must concentrate the specific metal well above the average crustal abundance.

Chalcopyrite is a copper iron sulfide (CuFeS_2). Without secondary enrichment, it forms an otherwise uneconomic deposit. The following steps describe how secondary enrichment forms a more concentrated ore deposit.

1. **Rainwater infiltrates** into an exposed surface of a **mineral vein/copper deposit (chalcopyrite)** and **percolates downward** through pore spaces.
2. In the **zone of oxidation, above the water table**, the **copper sulphides** (in chalcopyrite) **are oxidised to copper sulfates** which are **soluble** so are dissolved and taken into solution, being carried downward by groundwater. This process is **leaching**.
3. A **barren leached zone** is left at the surface which now contains a far lower concentration of copper. It has a **surface cap of iron oxides** which is **impermeable** and is known as a **gossan**. This is a useful **exploration target** since it suggests the presence of more economic ore deposits beneath.
4. Copper sulphides are carried in solution until they meet the water table. Just **above the water table**, brightly coloured blue (**azurite**) and green (**malachite**) deposits of **copper oxides and carbonates** are deposited as they precipitate out but these are usually of **minor importance**.
5. **At the water table**, conditions change from **oxidising above to reducing (anoxic) below**. Copper sulfates are **reduced to copper sulphides** which precipitate out as they are **insoluble**. These secondary copper sulphides form a concentrated small volume of **high grade 'secondary' copper core**, known as an **enriched deposit**. The high-grade enriched deposit **overlies the lower grade primary** deposit at depth.

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The water table contact is marked by deposits of **malachite** and **azurite** blue-green copper oxides, again with little economic value, but indicate a zone of interest.

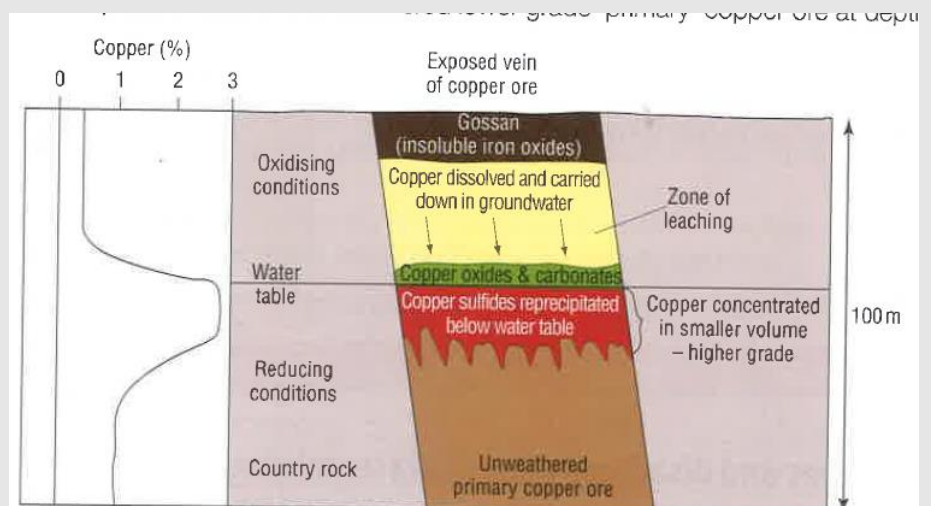


Figure 1 Cross-section showing how secondary enrichment occurs

Mining companies often **mine the area of secondary enrichment** first in order to **offset the capital costs of exploration and development**.

This is an important factor in the exploitation of a specific type of low-grade, high tonnage hydrothermal copper deposit known as a porphyry copper deposit.

Do not confuse secondary enrichment with residual deposit formation.

Similarities		Differences	
Secondary enrichment	Residual deposits	Secondary enrichment	Residual deposits
Both involve chemical weathering, hydrolysis, leaching and soluble substances being removed.		Secondary enrichment results from metals being leached and transported downwards in solution.	Residual deposits result from all soluble gangue minerals being leached and transported away in solution, leaving in the impermeable rock close to the surface.
Both involve the infiltration of rainwater which percolates down through pore spaces.		The ore is deposited in anoxic, reducing conditions below the water table.	The ore forms in oxidising conditions above the water table.
		Minerals are soluble / made soluble	Minerals are insoluble
		Mainly sulfides	Mainly oxides and hydroxides

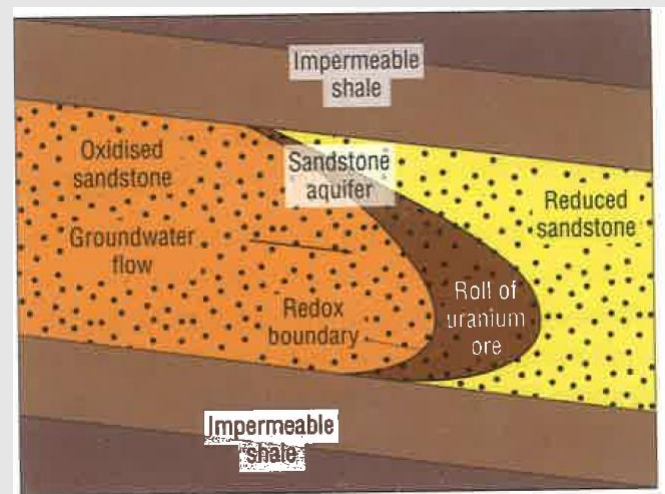
URANIUM ORE DEPOSITS IN SANDSTONE

Uranium is an important metal found as a **trace element in many igneous rocks**, but at concentrations too low for economic extraction.

It is radioactive and the isotope Uranium-235 is used as an energy resource in nuclear power stations.



1. **Uranium minerals (uraninite) exposed** at the Earth's surface undergo chemical weathering due to the **oxidising conditions** to form **soluble uranium ions** in solution in surface and groundwater.
2. The groundwater **percolates downward** carrying the uranium ions in solution.
3. **Buried fossil river channels** containing **porous and permeable** sandstones make good **small-scale aquifers**.
4. When groundwater meets a change in conditions, from **oxidising to reducing**, uranium ore minerals are **precipitated** in these **palaeo-river channels**.
5. **Curved or roll-type** uranium ore deposits form at **oxidation-reduction boundaries**. This boundary is at the **water table surface**.



In many sandstone-hosted uranium ore deposits, there is a close association between the **uranium ore and organic matter**. It is highly likely that **sulfur-reducing bacteria** present in **decaying vegetation** are involved in the ore-forming process.